In vivo ^{31}P–{^{1}H} Echo–Planar Spectroscopic Imaging of the Human Brain

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Introduction

Echo–Planar Spectroscopic Imaging (EPSI) is one of the fastest spectroscopic imaging (SI) techniques to obtain localized *in vivo* MR spectra. Since Posse *et al*. demonstrated the feasibility of ^{1}H EPSI for brain metabolite mapping [1] this technique was applied to various ^{1}H MRS studies. Concerning EPSI with other nuclei, the technique has been explored in a time-resolved ^{31}P study of phosphocreatine (PCr) in the human calf [2], while EPSI of phosphorous-containing metabolites in the human brain has, to our knowledge, not been considered so far. Here we present the development of eight NOE (nuclear Overhauser effect) enhanced ^{31}P-{^{1}H} EPSI sequences with short TE which permit two dimensional SI of the human brain providing high resolution ^{31}P-spectra with various spectral widths.

Methods

All measurements were performed with a clinical 1.5 T whole-body tomograph (Magnetom Vision; Siemens Medical Systems, Erlangen, Germany) equipped with a second rf transmit system operating at ^{1}H frequency and a double-tuned (^{1}H/^{31}P) circularly polarized head coil (RAPID Biomedical, Wuerzburg, Germany). The structure of our ^{31}P-{^{1}H} EPSI sequences is shown in Fig. 1. First a rectangular rf pulse is applied at ^{1}H frequency for NOE signal enhancement, followed by a slice-selective rf pulse for excitation of ^{31}P spins, a phase-encoding gradient, and an oscillating (sin) readout gradient. The latter generates a train of 256 pairs of gradient echos where each echo is sampled nonlinearly in time to obtain equidistant *k*-space sampling. Sequence parameters were optimized regarding localization, S/N, and spectral quality in experiments with different model solutions. The temporal position of the NOE pulse was chosen according to [3] for maximal enhancement. Flip angles were optimized using T_1 measurements with unlocalized inversion recovery and subsequent Ernst-angle excitation. As in conventional 2D ^{31}P SI, matrix was 8×8, while voxel sizes were in the range of 53–100 ml (16-25 ml interpolated). Eight different *k*–space trajectories with gradient ramp times ranging from 110 µs to 800 µs were designed to obtain ^{31}P EPSI data with spectral bandwidth (bw) between 313 Hz and 2.27 kHz. Short delays are possible, with minimum TE/TR= 1.2/140 ms resulting in minimum acquisition time (t_{AQ}) of only 1.2 s (8×8 matrix). Data were processed offline with an inhouse developed software package. Odd and even echos (256 time points each) were reconstructed separately. After reordering, ^{31}P EPSI data could be postprocessed like conventional SI data sets including spectral- and spatial zero filling. Finally, after phase correction, odd and even echo spectra were added to obtain maximal S/N. Spectral analysis, fit and calculation of metabolic images were done with *SiTools* [4] and *jMRUI* [5].

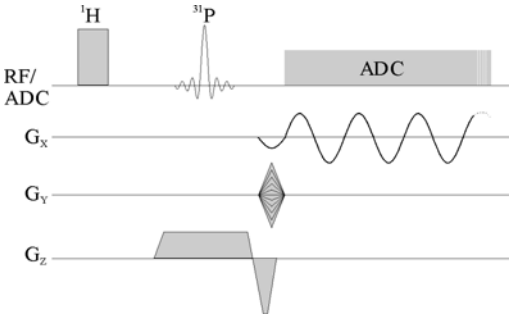

Fig. 1 Pulse sequence of ^{31}P-{^{1}H} EPSI with ^{1}H pulse for NOE signal enhancement and sinusoidal readout gradient G_X.

Results and conclusion

Phantom experiments showed that S/N of ^{31}P-EPSI is 25-30 % lower than S/N of conventional SI with the same voxel size and measurement time. This differs by only 5-10 % from theory [6]. Tests of reproducibility showed variations of S/N of 5-8 %. Five sequences with a spectral bandwidth between 1 and 2 kHz were used to obtain good-quality ^{31}P *in vivo* brain spectra from transverse, oblique slices of ten healthy volunteers (3 f, 7 m; age 24-47 y) with 7 resolved resonances assigned to the well–known metabolites of ^{31}P MRS: PCr, phosphomonoesters (PME), inorganic phosphate (Pi), phosphodiesters (PDE) and the multiplets of adenosine 5'-trisphosphates (α,β, γ-ATP). Flip angle was optimized for PCr: with unlocalized T_1 measurements of six subjects we obtained an average T_1 of 4.6 s for PCr and hence a flip angle of 17° (TR=200ms). Various measurements with different acquisition times, voxel sizes (minimum interpolated voxel size 16 ml) and bandwidths were performed. Fig. 2 shows representative ^{31}P spectra with different bandwidth recorded from two volunteers.

These results convincingly demonstrate the feasibility of ^{31}P-{^{1}H} EPSI of the human brain, providing robust and fast acquisition of high-resolution phosphorus spectra *in vivo*. The extremely short measurement time for a single ^{31}P EPSI shot (t_{AQ}=1.2 s) permits high-temporal resolution, localized analysis of ^{31}P metabolite levels even at very short stimuli. We are now developing such a functional MRS study.

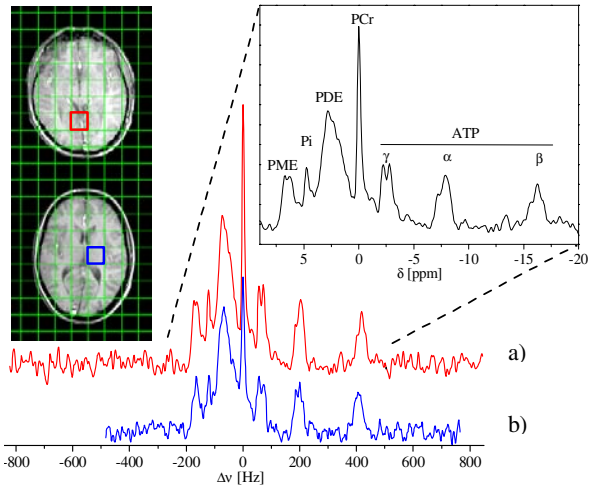

Fig. 2 Spectra from 2D localized NOE-enhanced ^{31}P EPSI of two volunteers: 8×8 matrix, *k*–space zero–filling to 16×16, FOV 400 mm, slice thickness 40 mm (voxels interpolated 25 ml), spectral zero–filling to 1024 data points, 6 Hz Gauss apodization, and baseline correction. a) Sequence with bw=1.67 kHz, TR=180 ms, NEX=500, t_{AQ}=12 min; b) sequence with bw=1.25 kHz, TR=240 ms, NEX=752, t_{AQ}=24 min.

References:

[1] S. Posse, C. DeCarli, D. Le Bihan, *Radiology* **192**, 733–738 (1994) [2] T. Wilhelm and P. Bachert, *J. Magn. Reson.* **149**, 126-130 (2001) [3] P. Bachert, M. Bellemann, *J. Magn. Reson.* **100**, 146-156 (1992) [4] A.A. Maudsley, E. Lin, M. Weiner, *Magn. Reson. Imaging*. **10**(3), 471–85 (1992) [5] A. Naressi, C. Couturier, J.M. Devos et al., *MAGMA* **12**, 141–152 (2001); http://www.mrui.uab.es/mrui/
[6] J.G. Pipe, J.L. Duerk, *Magn. Reson. Med.* **34**, 170–178 (1995)